SOME HYDROLOGIC EFFECTS OF CLIMATE CHANGE FOR THE APALACHICOLA, CHATTAHOOCHEE, AND FLINT RIVER BASINS

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INTRODUCTION

The Apalachicola-Chattahoochee-Flint (ACF) River basin drains about 19,600 square miles in Georgia, Alabama, and Florida. About 2.5 million people live in the basin which includes much of the metropolitan Atlanta area. Surface water in the basin is used for cooling in thermoelectric-power generation, public water supply, commercial and industrial activities, recreational activities, agricultural activities, and hydroelectric-power generation.

Changes in regional climate caused by increases in atmospheric concentrations of carbon dioxide (CO2) and other gases could change the amount of water available for use in the ACF Basin and thus affect water management practices.

Climate Model Predictions. General circulation models (GCM) indicate that rises of several degrees Celsius in average temperature, accompanied by changes in average precipitation amounts of several percent, are plausible. Table 1 shows predicted difference between model output for present levels of CO2 and model output for doubled CO2 for both monthly temperature and precipitation at a model node near the ACF basin for three GCM's. The three GCM's are the Goddard Institute for Space Studies (GISS) model, the Geophysical Fluid Dynamics Laboratory (GFDL) model, and the Oregon State University (OSU) model. The GCM output data were provided by the National Center for Atmospheric Research (Roy Jenny, National Center for Atmospheric Research, written communication, 1988).

If such hypothetical changes do occur in the basin over the next few decades, they could impact the seasonal distribution and amount of water available. Any change in water availability is of considerable interest to water resources planners and managers. A number of recent studies of the effects of climate change on a region have involved regional water-balance models and climate change scenarios (Gleick, 1986; Flaschka and others, 1987; Bultot and others, 1988 and McCabe and Ayers, 1989). A similar approach is used in this study.

Methods. To gain insight into possible effects of climate change on water availability in the ACF Basin, two models will be linked. The first model is a monthly water balance model that converts temperature and precipitation values generated by a random number generator to monthly streamflow values that simulate monthly runoff for given climatic conditions. These monthly streamflow values are input to a second model that simulates the operation of reservoirs and diversions within the basin. At the time of this report only preliminary runs of the water balance model have been made. Complete results will be reported in a subsequent paper.

The output for the two linked models includes time series of reservoir levels and streamflow at key points in the basin. These time series will be analyzed to evaluate the effects of climate change and modified operating rules for the basin on drought risks. Model results will be given for a base case, in which monthly temperature and precipitation statistics are unchanged from historical records, and for several plausible changed-climate scenarios.

Table 1. Difference in Average Monthly Temperature, ΔT (in degrees Celsius), Between Single and Double CO2 Runs for Indicated Models and Double CO2 Precipitation Expressed as a Percentage of Single CO2 Precipitation, %P. Data are for the GCM Model Node Nearest the ACF Basin.

	General Circulation Model					
Month	GFDL		GISS		OSU	
	ΔT	%P	ΔT	%P	ΔT	%P
Jan	3.4	77	4.8	67	5.7	96
Feb	3.6	105	4.6	168	3.4	98
Mar	4.3	115	6.7	62	4.5	67
Apr	5.3	115	5.6	80	4.2	78
May	3.7	84	3.5	142	3.4	107
Jun	6.3	101	3.7	121	3.9	96
Jul	7.6	65	3.7	150	3.3	103
Aug	4.5	42	4.0	88	2.9	120
Sep	6.2	81	7.0	109	3.8	148
Oct	4.8	67	4.9	61	4.1	100
Nov	5.5	108	8.3	85	2.5	87
Dec	5.4	107	6.1	73	3.0	98

GENERATION OF CLIMATE SCENARIOS

Temperature and precipitation values will be generated that simulate climate for the next 50 years. The values are created by randomly generating a deviation from a mean monthly value of precipitation or temperature for subareas of the basin. The deviations from the mean monthly values for the subareas are generated using a multi-site Markov model (Matalas and Wallis, 1976). The impact of uncertainty in the parameters of the multisite generating model is included in the generation process using the scheme described by Stedinger and Taylor (1982).

Climate change is simulated by adding an incremental amount to the generated temperature values and increasing or decreasing precipitation by an incremental percentage. The total amount added to temperature or total percentage change in precipitation is determined by the difference in single and double CO2 runs for the three General Circulation Models (GCM's) in Table 1 or by other prescribed scenarios.

Although plausible, these climate change scenarios are not considered to be accurate predictions of climate change in the basin under doubled CO2 conditions. The state of the art of climate modeling has not progressed to the point where climate change for a region as small as the ACF basin can be accurately predicted (Gleick, 1989). Until the time when GCM's can provide accurate, detailed information on a regional scale, the hydrologists and water planners must rely on other methods, including using regional water-balance models to explore a wide range of climate change scenarios.

WATER-BALANCE MODEL

Gleick (1987) concludes that water-balance models similar to the model developed by Thornthwaite (1948) are particularly suited for use in studying the effects of projected climate changes on water resources. Standard methods of calculating water balances are described in many publications including Thornthwaite and Mather (1955) and Mather (1980). Numerous computer programs for the calculations are also available (see Willmott, 1977; Black, 1981; and McCabe and others, 1985).

In water-balance models, whenever precipitation exceeds potential evapotranspiration, soil moisture increases until it reaches its water holding capacity. If soil moisture is at its water holding capacity, precipitation in excess of potential evapotranspiration becomes water surplus, which is available for runoff. Whenever precipitation is less than potential evapotranspiration, moisture is withdrawn from the soil.

Application of a water-balance model to convert monthly temperature and precipitation values to monthly streamflows requires choosing model parameter values to describe certain hydrological and physical characteristics of the ACF basin. These parameter values include average water-holding capacity, basin lag, and direct runoff parameters. The water-holding capacity of the soils in the basin varies greatly from site to site, depending upon land use and soil depth. Basin lag is the fraction of water surplus available for runoff that promptly leaves the watershed. Values of less than one are chosen due to the runoff delaying effects of ponding and subsurface flows. Direct runoff, a, is the fraction of precipitation that gathers in gullies, streamlets, and channels and runs off in a relatively short time.

In daily-time-step water balance models, when precipitation, Pd, exceeds daily potential evapotranspiration, PEd, and soil moisture is at field capacity, a water surplus equal to Pd - PEd is available for runoff. However, in dealing with monthly values of precipitation, Pm, and potential evapotranspiration PEm, the surplus calculation needs to be modified to account for the uneven distribution of precipitation throughout a month (Schaake and Chunzhen, 1989). This adjustment is made by calculating the monthly surplus when soil moisture is at capacity by Pm-fPEm.

The water balance model parameters described above for the Chattahoochee River basin above Atlanta were determined by fitting model runoff predictions to observed monthly runoff values for the Chestatee River at Dahlonega and Big Creek at Alpharetta for the period 1961 to 1990. Figure 1 shows how well the model fits observed data for part of the calibration period.

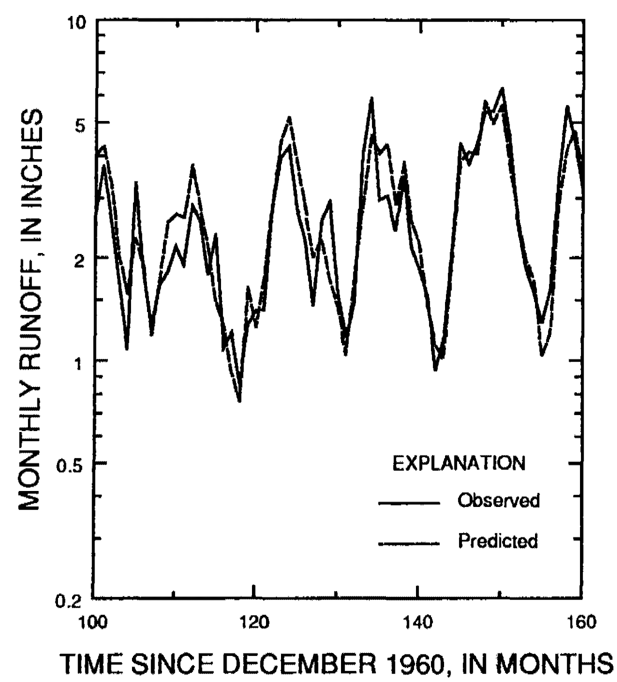

Figure 1. Predicted model runoff and observed runoff for Chestatee River at Dahlonega and Big Creek at Alpharetta.

Studies have suggested that the effects of increased temperature on evapotranspiration rates may be counteracted when atmospheric CO2 concentrations increase because of increases in stomatal resistance, changes in cloud cover, or some other factor (Rosenburg and others, 1990). These counteracting effects can be included in the model by decreasing the value of f, thus increasing runoff. However, for the model runs described herein, the value of f was held constant.

BASIN MODEL

A basin model will be developed that keeps track of input and output flow volumes at various nodes in the basin. Key nodes include the major reservoirs, the Chattahoochee River at Atlanta and West Point, and the Apalachicola River at Apalachicola, Florida. Input and output volumes are determined by the operating rules of the basin, diversion rates, consumptive water use rates, and "natural" flows from the water balance model. Diversion rates, water-use rates, and target flow minimums change according to the current amount of water storage in the major reservoirs. By keeping track of river flows during a model run, drought risk can be computed as the number of months when the simulated flows were below a specified level divided by the total number of months in the run. Drought risks and flow at key locations in the basin can be computed for different climate conditions, operating rules, diversion rates, water-use rates, or reservoir sizes.

PRELIMINARY MODEL RESULTS

At this time only the water balance model has been run for the portion of the Chattahoochee River basin above Atlanta. The results shown in table 2 indicate increases in the percent of monthly runoff values that are below 2 inches, 1 inch, and 0.5 inches if climate changes in accordance with the scenarios based on GCM output. The scenario associated with the GFDL model indicates the greatest increase in number of low flow months, and the OSU based scenario indicates the least increase in low flow months due to doubling of atmospheric CO2 concentrations.

Table 2. Percent of Simulated Monthly Runoff Values Falling Below Indicated Runoff Levels.

	Monthly runoff levels, in inches		
Scenario	0.5	1	2
Historical record (1960-1989)	2.0	16	51
Base run (no climate change scenario)	2.2	17	50
GFDL scenario	8.5	33	62
GISS scenario	8.7	32	65
OSU scenario	4.8	20	62

CONCLUSIONS

A regional water-balance simulation model such as the one described herein can be used by hydrologists and planners to evaluate the effects of possible climate change scenarios, changes in general operating rules, changes in water use or changes in storage capacities on low flows in the ACF basin. Although plausible, these climate change scenarios are not considered to be accurate predictions of climate change in the basin under doubled CO2 conditions. Preliminary results for hypothetical climate scenarios based on output for three popular GCM's indicate that lower flows will occur more frequently if the regional climate warms and monthly precipitation decreases during critical summer months.

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